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Reprinted from the BRITISH MEDICAL JOURNAL, *May 30th, 1914.*

ON

INFANTILE PARALYSIS

(*ACUTE ANTERIOR POLIOMYELITIS*),

Its Early Treatment and the Surgical Means for the Alleviation of Deformities.

Being the Annual Oration to the Medical Society of London.

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WHEN your Council graciously invited me to deliver the oration before this distinguished society I fear I had not the courage to refuse. The honour was such that for a time I did not realize my grave responsibility, and now I deplore the consciousness that I do not possess those gifts of erudition and imagination which have charmed while they enlightened you in the past. Despite the wide field you have allowed me, the choice of subject has not been easy. Devoted as my life has been to the more practical and clinical aspect of surgery, my horizon is, for this very reason, less comprehensive. I must therefore crave your kind indulgence while I deal in a simple and plain fashion with such principles as I have found helpful to me in dealing with infantile spinal paralysis. The subject is so vast and the technicalities so manifold and intricate, that I intend to dwell merely on those procedures which I have tested through the years, and which have served me best, and to refer you to the work of others who labour in different ways in other fields. One must possess a buoyant spirit and boundless enthusiasm to treat these affections with advantage, and one must have fixed principles of wide application. If these principles are fundamental, we must give them our whole-hearted allegiance, and not merely pay them a transient homage. We can then afford to await results, and not take heed of difficulties or yield to the counsels of despair. Like a mariner who meets an adverse wind, we must not lack confidence, but exercise every art we know to land safely where we would.

There are few subjects which have aroused so much interest during recent years as that of infantile paralysis. This is due to its greater prevalence, its proved infectiveness, and the great advance in the method of attack which

modern surgery has introduced. Unfortunately, very little has been done in this country, as compared with America and Germany, by way of the collective investigation of etiological factors.

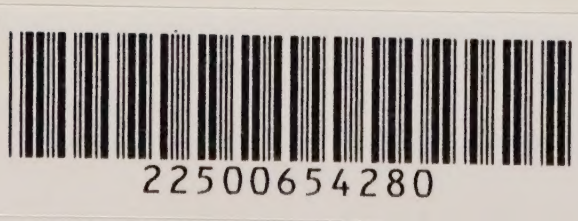
The Fundamental Importance of Early Treatment.

The early treatment of poliomyelitis falls of necessity into the hands of the medical man in attendance. It is on rare occasions only that the surgeon sees a case during the first few days, and then only when the onset of paralysis is accompanied by pain. Such cases are by no means rare, the pain being most marked in the spine and limbs. Rigid fixation of spine and limbs gives more relief than any other procedure I know. Indeed, I should make it a general rule that in every case, whether pain be present or not, the head and spinal column should be kept at rest in accordance with the general principles which guide us in the treatment of an inflamed area. The surgeon is often asked when treatment should be started. The answer is, "At once," and during the acute and early convalescent stages the surgical treatment may be summed up in the word "rest," if this term be allowed to include the prevention of postural errors—such as tend to give an initial bias towards deformity.

Active treatment should commence only when the tender stage has passed. If a possibility exists that during the tender stage active myelitis is present, there can be, in my opinion, no sound reason for the use of massage or electricity. This tender stage may last from three to eight weeks—in exceptional cases longer. We all know how difficult it may be to allay the parental apprehension during this period of surgical inactivity, but I have never found trouble when the reasons for the delay were made clear.

Our treatment should consist in placing the paralysed muscles in a position of relaxation, in the use of very gentle massage and in active movements, so conducted that no strain of the relaxed muscles be allowed. For instance, if the flexors of the ankle are being kept relaxed, the foot should in no case be allowed into the position of equinus during massage, and any active movements should consist of flexion beyond, but never below the right angle. Of this fact I have had many definite experiences. Some degree of voluntary muscular action should be encouraged as soon as possible, but at first there should be no movement of the joint, for the muscle is not strong enough to act against resistance. Thus, in a case in which the lower limb is fixed, with the knee extended in order to rest the quadriceps extensor, the first clinical sign of recovery will be a voluntary twitch of the muscle. The child's attention should be directed to this and he should be taught to practise it. The masseuse can soon lay a finger on the upper edge of the patella, and so give a little added resistance. To allow the child to flex the knee at this stage would be to court disaster.

The character of the massage is very important and much harm may result if it be too vigorous. In this early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stage it should consist of light vibratory effleurage applied as if to the skin, particularly over the area supplied by the same segments of the spinal cord as supply the impaired muscles. Rough kneading at any stage of the disease will damage fragile muscle fibre and diminish muscle tone.

Another question we are early called upon to decide is the possibility of recovery of weakened or paralysed muscle. This is often a very difficult question. It has always been the teaching that a muscle which exhibits the reaction of degeneration is outside the pale of hope, but years ago I drew attention to several instances where recovery took place in muscles where this reaction was carefully noted on the chart. This observation has been borne out and emphasized by many observers abroad. We may be certain that if a muscle reacts to faradism it will recover, but in actual practice the converse does not always hold. This may be due to the real difficulty that exists, sometimes even under anaesthesia, in making reliable observations in small children. The result is that in most active clinics complete electrical observations are rare. This would be a serious omission were no other means available to obtain trustworthy evidence sufficiently accurate to be a practical guide. We can, however, secure, with a little patience and gentle approach, much valuable information from the conscious effort of the child. A muscular response may be elicited by even so slight a stimulation as a gentle scratch by the head of a pin, a gentle pinch, or by tickling the sole. No information can be gained from a child under the influence of fear, and if the child be too young to understand what is desired of it, it will probably be too young to justify any operative procedure. In such instances doubtful muscles should be treated as if recovery were to be expected.

It is often asked at what stage should we give up all hope of the recovery of a paralysed muscle. This depends largely upon treatment, and upon an accurate knowledge as to whether the paralysed group is suffering from the effect of overstretching, or whether there has been a destruction of the dominating cells. I shall deal more fully later with the functionally disabled muscle of which H. O. Thomas wrote forty years ago. If under appropriate treatment a muscle makes no improvement in twelve months we may assume that its function is lost.

Danger of the Overstretching of Disabled Muscles.

Before we discuss the general principles which should influence us in the operative treatment of poliomyelitis, it is necessary to enter more fully upon the question of the overstretched or functionally disabled muscle as contrasted with the muscle truly paralysed by permanent organic change in the spinal cells. I make no apology for this, for I regard the success or failure of mechanical treatment, of tendon transplantation, of neuroplasty, and even of arthrodesis, as depending largely upon the recognition of the facts revealed by the behaviour of muscles under strain.

I would ask your attention to the impairment of muscles

themselves, of the nerves supplying them and of the nerve cells in the spinal cord, and for an illustrative and simple example of the three conditions I would refer you to the deformity we call "drop-wrist."

Some years ago I saw a patient who had divided the tendons on the front of his wrist. The surgeon carefully sutured them, and to make sure of secure union he bandaged the fingers and wrist in a flexed position. He kept them in this position for some weeks. The wound in the wrist and the divided tendons had healed, but the patient had no power of extension. As this disability persisted, I was consulted, and reversed the position of the hand. The muscles, which had been stretched by flexion, and which had undergone an adaptive lengthening, if I may use the phrase, now shortened by being relaxed, and soon resumed their function.

I have elsewhere alluded to experiments on friends, where, after twenty-four hours of moderate stretching applied to groups of muscles, a functional paralysis has resulted, rapidly recovered from when the muscles were relaxed. Similarly, if careful inquiries be made in a definite proportion of cases of drunkard's palsy, you may eliminate as a causal factor pressure upon the musculo-spiral nerve.

Next, I would refer to blocking of nerves by minor lesions, such as a temporary pressure upon the external popliteal nerve, or an effusion of blood within a nerve sheath, as sometimes occurs in Erb's birth palsy, and in the trauma of the brachial plexus. In consequence of the blocking of the nerve path, muscles are paralysed, the paralysed muscles lengthen and again a dropped foot or a dropped wrist occurs, from which the patient will not necessarily recover when the nerve block is removed, unless the overstretched muscles are given the opportunity of shortening. For example, a man of 40 consulted me for paralysis following fracture of the humerus. His doctor explained that he lost power in his musculo-spiral nerve at the time of the accident two and a half years previously, and his extensors had been useless ever since. It was suggested that I should explore the nerve, which had not been completely severed, and then free it from callus or whatever pressure it was subjected to. The patient was quite unable to extend his wrist. The wrist and fingers were placed in full extension and the muscles massaged. In ten weeks the restoration of balance between the rival muscular groups was attained.

Then there are the lesions of nerve cells in the spinal cord, such as are due to lead, or the toxins of micro-organisms, as in poliomyelitis. In these cases the nerve cell is not the only tissue which is impaired. Although a large measure of recovery in paralysed muscles may take place, others may remain functionally disabled in spite of massage and electrical treatment, and yet this disablement may be due, not to destruction of the motor nerve cell, but to atrophic changes in the muscle as a result of disuse and stretching. Clinical experience has shown me

that very often in cases of dropped wrist due to infantile paralysis, recovery will take place many years after the original lesion if the muscles are kept continuously relaxed by dorsiflexion. In cases of long duration the hand is sometimes kept dorsiflexed for over twelve months without being once allowed to flex. The lessons I have learnt from watching the clinical progress of these cases have led me to believe that we are not justified in considering cases of infantile paralysis as merely an injury of the spinal nerve cell by a toxin, and that recovery depends simply upon whether the nerve cell survives or succumbs to the poison. We must rather consider the whole nerve muscle apparatus. The lesion to the nerve cells may have been transitory, but in the meantime the muscle has been relaxed and overstretched by gravity, by habitual posture, or by overaction of opposing muscles. The muscle has wasted from disuse, and become incapable of responding to such feeble impulses as come to it from an impaired nerve cell, consequently, the normal afferent impulses do not pass up to the nerve cell, because the muscular action which originates them is absent, and the whole reflex apparatus, by which the spinal nerve cell and muscle react on each other to their mutual benefit, is put out of gear. Experiments have proved that excision of muscles leads to chromatolysis in the corresponding spinal nerve cells. Our ideas of the changes which take place in the process of degeneration and regeneration in a divided nerve trunk have been much enlarged in recent years. Are we not warranted in assuming that, though in many cases the original disease has not killed the motor cell in the spinal cord, recovery of muscular action does not take place spontaneously because the whole apparatus—nerve cell, nerve trunk, and muscle—are in a state of disuse atrophy, and continue to remain so, because the muscle, from its mechanical disadvantage, cannot perform its function of contracting, which is an essential part in the circle of reflex and trophic influences?

Not only has all this a very important bearing upon the early treatment of the affection, but it is also the keynote to the fate of a newly transplanted tendon. If efficient treatment be begun at the onset of the disease, care taken that the knees and hips are not kept continuously flexed, that the weight of the bedclothes does not keep the toes pointed, but that the feet are held at right angles, that the biceps, brachialis anticus, and deltoid are not continuously stretched by the arms hanging to the side, then much of the residual paralysis may be averted, for as the first severity of the spinal lesion passes off isolated groups will not be left at a mechanical disadvantage.

The factors that tend to the undue straining of muscles following a paralysis are:

Posture generally influenced by gravity.
Inefficiently opposed muscular action.
Deflection of body weight.

The deformities become fixed when more powerful opponent tendons become structurally shortened.

In the shoulder, where the deltoid is so often affected, the arm should be kept abducted from the first. This can be accomplished by any method devised to fix the hand behind the head. In paralysis of the brachialis anticus and biceps, the elbow, by the aid of a sling, should be kept acutely flexed. In paralysis of the extensors of wrist and fingers, as I have already indicated, the wrist should be kept acutely dorsiflexed. In paralysis of the peronei the foot should be kept everted; it should be kept inverted when the tibials are involved, with the toe pointed when the calf muscles are implicated; and at right angles when the flexors of the ankle and the extensors of the toes are at fault; and so with other groups of muscles. The splints applied should be such as to maintain relaxation while massage is conducted, and should be so constructed that they can be held in position without the necessity of putting pressure by hand or bandage over muscular tissue. This is a practical point of considerable importance in view of the necessity there is to guard the paralytic muscle against lessened blood supply. If electricity be desired the constant current can be used, but its advantages cannot be compared with those of posture, massage, and exercise.

It will be realized by this that under no circumstances should even momentary stretching of the relaxed muscle be permitted, as the success of treatment depends upon undisturbed continuous relaxation. It may be asked, When should this treatment be discontinued, and what are the tests of recovery? We will take the wrist, elbow, and knee as example.

In the wrist, as soon as the hand, which is being kept dorsiflexed, can be voluntarily moved into still further dorsiflexion, the angle of the splint may be reduced by a few degrees, and if the power of dorsiflexion does not diminish from week to week as the angle is being slowly reduced, recovery can be assured. This relaxation should only be allowed during the daytime; in bed the original angle should be maintained.

A similar test should be applied to the elbow, which is slung at an acute angle. As soon as the patient can voluntarily diminish the angle, the sling may be slowly dropped, the closest observation being maintained upon the character and strength of the muscular contraction. I will relate one of many similar cases which come to my mind, in order to impress this phase of treatment upon you. A small child of 4 years, paralysed at the age of 2, was brought to me with paralysis of all the muscles of the upper arm, but he retained some power in the flexors and extensors of the fingers. There was not the slightest effort made to use the elbow. I explained to the medical man, perhaps too briefly, the principles upon which I trusted when I slung the child's elbow at an acute angle. Some two months later I received a very enthusiastic letter from the doctor. He told me that the brachialis anticus and the biceps were both working well, and that he had removed the sling and sent the boy to the country.

I expressed my fears, and in a few days a letter, penned in a minor key, spoke of disaster. The muscles, submitted to too much strain, had been vanquished in the struggle. The elbow was then again acutely flexed, and from time to time lowered under supervision, when recovery took place.

In the knee, where the quadriceps is involved, the test is conducted on similar lines. The knee is kept extended on a splint, and when recovery begins to take place the patella is seen to move. Later, when the movement of the patella is stronger, the test is carried further ; the splint is temporarily removed and the patient's heel made to rest upon the table. If the patient can lift his leg ever so slightly from the table, the knee remaining extended, further graduated liberty of action may be allowed.

In the early stages of treatment the only operative procedures which I judge to be expedient are those necessary to allow postural relaxation of the over-stretched muscle. These will consist mainly of tenotomies, more particularly in connexion with the Achilles tendon, and divisions of bands of fascia, very often supplemented by the removal of a skin area, in order to obviate the disloyalty and carelessness of parents, who do not see the importance of keeping a foot constantly and for a prolonged period in the over-corrected position. Results are necessarily variable and disappointing under such conditions. To guard against this possibility I remove an oval area of skin sufficiently large to ensure that when the wound is sutured the foot is held in an over-corrected position. In talipes equinus skin is removed from the front of the ankle in sufficient quantity to retain the feet at right angles. In equino-varus the skin is removed from the outer side and front of the ankle, and so the nature of the operation differs from group to group.

It is of great importance to provide, as early as one can, for some degree of normal functional exercise of the whole limb. This is best attained in the lower limbs by allowing the patient to walk. It is during this stage in particular that we have to guard against those deformities which result from erroneously deflected body weight. The splints should be light and so designed that the alignment of the limbs and the distribution of weight upon the joints be accurate. My experience is that the surgeon usually sees his patient for the first time long after the initial stages are passed. He is then asked to deal with actual and functional paralysis, with superadded deformity of varying degree. It may be laid down as an axiom that no operation, such as arthrodesis or tendon transplantation, should be discussed until all deformities have been corrected and retained in correction for at least a fortnight.

The Correction of Certain Deformities.

This is hardly the occasion to detail the methods employed for the correction of the several deformities which are presented to us. A few general remarks, however, are necessary if my address is to be of practical use.

Contracted knees and hips should be overcome slowly. It is highly injudicious to exercise much force; indeed, force in the form of redressment, apart from its dangers, is very inefficient. It is much easier to straighten the fixed limbs of arthritis by force than those of poliomyelitis. Division of tendons, fasciae, and even ligaments may be freely performed. A tendon, however, which may at some future date be required for transplantation should be spared from tenotomy and be gradually stretched instead, for adhesions are very apt to form over old scar tissue. A common deformity which is so often the despair of the surgeon is that in which he finds both limbs contracted at the hips and knees, and where the spine is lordosed, the pelvis oblique, the knees in genu valgum, and the feet in equino-varus. My mode of attack in such a case would consist in the division of the tensor fasciae femoris, and of any other tight structures in that neighbourhood, moulding the feet into a valgoid position, dividing the Achilles tendons, and then laying the patient on a splint or frame of the Thomas type, adding a simple extension to correct the pelvic obliquity, and with a bandage to the outside bars of the splint to overcome the knock-knees slowly. The procedure is simple and invariably effective. The lordosis will usually be overcome in three or four weeks with barely any discomfort. We must employ gravity as our ally by so placing the limbs that time is not wasted. Even here common sense and practical experience must be of use. For instance, after division of the tensor fasciae the limbs must be kept slightly hyperextended and rotated inwards, otherwise no strain is applied to tight structures. Where deformities are extreme, lordosis, no matter how pronounced, should be absolutely corrected if we are to attain the best functional result. Sufficient attention is not given to this very important point.

Many authors warn us to be careful of evils which may follow division of the Achilles tendon. The substitution of a calcaneus deformity for an equinus would be serious. This is a real danger in spastic cerebral paralysis, and subcutaneous tenotomy in such a condition should never be performed. In my own experience—and I have divided the tendo Achillis and immediately corrected the deformity many thousands of times—non-union has resulted in three instances only. Despite this good fortune, in adults with extreme deformity I generally employ one of the many methods of subcutaneous plastic division. The lengthening so much feared is the result of faulty after-treatment; the uniting tendon is allowed to stretch before it is sufficiently strong to bear the body weight. Another common mistake is to place a small pad over the site of puncture, so permanently separating one end of the tendon from the other. In a limb with three inches of shortening it is tempting to leave the tendon shortened and let the patient walk on tiptoe, but it is a temptation to be resisted, for we must always think of the muscle group which is being stretched with its possible potentiali-

ties of recovery. If recovery does not take place, the resources of surgery are not ended, and means must be taken to give further stability to the joint.

Let us recognize, therefore, as a fundamental principle that every fixed deformity should be corrected before any operations are performed for securing improved muscular function. These deformities may be overcome by manipulation, tenotomies, fixations, and extensions, and more rarely by ostectomies and the removal of bone. These preliminaries, however, are inevitable, and allow of no exception. I emphasize this because I have frequently seen failure in tendon transplantations due solely to their neglect.

Tendon Transplantation.

In briefly discussing the question of tendon transplantation I shall make no attempt to enter into the details of various operations, but will be content to point out what in my experience are the indications for its performance, the elements that make for success, and the causes of failure.

The object of a transplantation is to improve or restore muscular balance. It is not justified unless it improves function. There is little satisfaction to a patient if the transplanted muscle merely responds to faradism, or even makes a feeble movement by an effort of the will. It must be, or give the promise of becoming, a substitute for the muscle it supplants. It can only be judged by its usefulness. It may be applied to restore the balance between opposing groups of muscles by helping a redistribution of power, or its attachment may be slightly transposed to prevent deformity. Or it may be applied, as it often is, as an accessory to arthrodesis or in conjunction with the use of silk ligaments. Now, if we were to be guided entirely by the charts that have been worked out as to the relative strengths of muscles, and if we were to abide by them each time we desired to transplant a tendon, we should probably be discouraged at the very threshold.

The tibialis anticus would be too strong to supplant the peronei, and the peronei too weak to act as a substitute for the tibial group. Although it is useful to possess the knowledge that the calf muscles are as strong as all the other muscles of the foot put together, we need not infer from this fact that in pes calcaneus no tendon transplantation need be tried. Healthy muscles can be developed to an extraordinary degree. Some years ago I was called upon to operate upon a boy whose peroneus longus slipped over the malleolus. This had happened for two years, and I was amazed at the great size of the muscle. On inquiry I found that the dislocation, which was voluntary, was always accompanied by an audible snap, and the youngster collected pennies by displaying his gift, and had thus greatly over-developed the muscle. Transplanted muscles by special exercise become similarly developed. The equalization of forces, therefore, is not essential, for nature has a large margin of adaptability, but for obvious reasons

an effort should be made to get all the help possible when we have to secure substitutes for a powerful tendon.

Clearly the most important factor in commanding success is a sound judgement on the part of the operator. He should definitely realize what he wants to do and the means at his disposal. He should not be content merely to know the action of the muscle he is transplanting, but he should judge also of the disability he creates at the part from which the tendon is removed. There is no sense in substituting one deformity for another. Transplantations are most successful when the paralysis is limited and when re-enforcement can be introduced from the close vicinity. The operator is the best judge of the value and strength of tendons. This can best be done by noting the active movements. Many a muscle which responds to faradism is not fit for transplantation. I have no sympathy at all with those surgeons who make large incisions to investigate the colour of the muscle fibre before they transplant. No operation should be done until evidence of sufficiently strong active movement in the muscle to be used has been obtained. Experience clearly indicates that we are justified in sacrificing abduction and adduction of the foot for plantar flexion and dorsiflexion, and that we can at any time sacrifice the mobility of the toes whenever the tendons are likely to be of use elsewhere. Paralysis of the calf muscles is the worst of all disabilities I have long ago discarded complicated varieties of transplantation, the subdivision of muscles, and the many forms of fixation into tendons, and I rely more and more upon simple and direct methods.

For a varus deformity I transplant the tibialis anticus; for a valgus the peroneus longus and the extensor proprius hallucis. For a partial paralysis of the calf muscles I shorten the tendo Achillis, pleat the posterior part of the capsule, fix the peroneus longus and flexor hallucis firmly into the insertion of the tendo Achillis, and remove an area of skin at the back of the ankle. Where the calf muscle is completely paralysed, after correction of cavus, I transplant the peronei and flexor hallucis, with any other available muscle from the sole, into the tendo Achillis. If all the muscles are paralysed, or almost all, my own two stage operation or that of Whitman, which involves the removal of the astragalus and a readjustment of body weight upon the ankle, is sound and effective. In paralysis of the quadriceps I transplant one or more of the hamstrings, and these practically complete my list of transplantations except for rare conditions. I rarely utilize tendons in the upper limb, although occasionally I find it necessary in the spastic type such as infantile hemiplegia.

There has been much discussion as to the method of implantation. I am in no manner of doubt as to the great advantage of transplanting into bone. Lange and Vulpius respectively advocate grafting into periosteum and tendon, but, when it is possible, a graft into bone gives far greater security. There may be a sound reason on rare occasions

for employing silk tendons, but I am quite satisfied that, wherever it is possible, the tendon should be directly implanted into bone.

Technique.

I can best indicate the technique I employ by describing the operation of transforming the peroneus longus into an inverter of the foot. The tourniquet is applied above the knee, and only removed when the wound is dressed and bandaged. This obviates bleeding, a source of danger to the security of the graft. An incision of about an inch in length is made on the outer side of the foot and the tendon is divided where it turns round the cuboid. A small incision is next made over the muscle, well above the external malleolus, and a smooth dissector is passed underneath the tendon, and it is pulled through the opening and wrapped in a sterile swab. A small incision is then made over or near the scaphoid, and a curved forceps is passed from this to the upper wound, preferably through fat, and moved about to make a free tunnel. The tip of the tendon is now held by the forceps and guided through the tunnel to its new insertion. Care must be taken that in its transit it runs as nearly as possible parallel to the tibialis anticus, and that there is no angle in any part of its course. The attachment may be made in one of two ways. A hole may be drilled through the scaphoid, or internal cuneiform, and the tendon passed through it. This is the method of choice. In a case in which the tendon is short, a groove may be made in the bone, and the tendon may be made to lie in it while the end is fixed in ligamentous tissue below. The wounds are then closed and the foot is bandaged in inversion. No silk is used around the tendon, which is secured by chromicized gut. The important part of the technique is, first and foremost, never to handle the tendon with forceps anywhere excepting quite at its periphery, to pass it through fat, to secure the transplanted end in firm unyielding tissue, and to see that the alignment makes for a direct pull. Experiments have conclusively shown that wherever a tendon is roughly handled adhesions form; for this reason it is well to compress the tendon with forceps at the point of its attachment, namely, at the end, but nowhere else. The causes of failure are largely due to errors of judgement and to faulty technique. This is suggested by the progressive improvement in our results. In many of my early cases the point of attachment yielded under the influence of strain; in others adhesions formed. This was due to want of delicacy in the handling of the tendon, to the character of the structure through which it was made to pass, and to want of directness in the pull. The tunnel through which the tendon is directed should be roomy, the track through which it passes should, where possible, be in one plane, it should not pierce different layers, it should never abruptly turn a corner, nor perforate an interosseous membrane. The transplanted tendon should not be called upon to correct deformity,

nor follow the convex aspect of a bone. It should not be allowed to travel immediately below the line of incision for fear of adhesions, nor be affixed to yielding structures. When its sheath can be preserved it is of advantage, but this cannot always be. Total transplantation is always preferable to partial, and when choice exists it is well to fix upon a muscle for transplantation whose function is similar to that which is paralysed. There is another point upon which I lay great stress, and that is an appreciation of the appropriate tension on the transplant. Under excessive tension muscle atrophies, while if the tendon is left too slack restoration of its function will be long delayed.

After-Treatment.

After the tendon is transplanted and before education begins, a somewhat prolonged period of fixation is needed, all strain on the graft being prevented. Three months or more may be needed by the calf muscles; in the case of the everters and inverters of the ankle, from four to six weeks; the extensors of the knee require considerably longer. Light celluloid or leather splints of a removable kind may then hold the joint in position for an indefinite period, to prevent the harmful exercise of body weight during walking. The splints should be removed two or three times a day during the whole of this period for the practice of massage and active exercises under resistance. In other words, every care should be taken to strengthen the transplanted tendon for its new responsibilities.

Seven or eight years ago Hoffa, Lange, Vulpius, and I were invited to give our experiences of tendon transplantation at the French Congress of Surgeons in Paris. We differed from each other in our respective procedures, but we all spoke in favour of the operation. Our colleagues in France were not so enthusiastic, and Kirmisson especially drew attention to the fact that, although immediate improvement occurred, it was generally followed by loss of function in the transplanted muscle. This has been referred to by many writers, and must be within the experience of us all. Why should a muscle which is working at first fail later? With hardly an exception it is because we do not recognize in practice the principles in regard to muscle stretching which I have discussed at such length in an earlier part of this address. Either the muscle has not been developed sufficiently to defend itself against an opponent, or during walking body weight has been allowed to bear injuriously upon it. These are both fundamental errors which are happily avoidable, and can, even when they have happened, be remedied by recourse to relaxation and massage.

I rarely operate upon children under 5, for three reasons: First, because of the technical difficulty in handling and fixing minute tendons; secondly, because we should be sure that sufficient time has elapsed to give the muscles a chance of recovery without operation; and, thirdly, because it is most important that the child should be sufficiently intelligent to give us help.

A fascinating problem to study is that of physiology or psychology as it affects the transplanted muscle. It is very difficult to understand how an inverter can be trained to evert the ankle and how it can be made to exercise its new function by an effort of volition. Vulpius suggestively refers us to the work of Galen, Duchenne, and Sherrington on the function of opponent groups, and draws attention to the well-known fact, which we have all observed, that, when we ask a paralytic, whose extensors are lost, to attempt extension of the toes, he uses the flexors instead.

This does not happen in a later stage. Both clinical and physiological investigations clearly prove that when a muscle or muscle group is stimulated to contract the opponent muscle or group is inhibited. It has been argued, therefore, that a hamstring, transplanted into the patella to reinforce the quadriceps extensor, will not contract simultaneously with the latter muscle. According to this view, which is supported by Murk Jansen, of Leyden, the only real benefit of this transplantation is that it makes the knee-joint steadier, and when the hamstrings contract in flexion the transplanted hamstring also contracts and prevents their uncontrolled action. Even if this were the whole truth of the case, the operation would be beneficial from the practical point of view. But it is not the whole truth; generally the transplanted tendon can be seen and felt to become tense simultaneously with the quadriceps extensor. In the present state of our knowledge, I venture to suggest that this dissociation of the action of the transplanted muscle from its own natural group, and its association with a new strange group, is comparatively easily attained in children under careful muscle training. Certainly in adolescents a long and uncertain struggle between the opponent groups is often observed, suggesting that the older the patient the more difficult is education. In my opinion this indicates the necessity for more careful consideration of our methods of muscle training rather than a hasty condemnation of the operative procedure.

Operations to Produce Increased Stability of Joints.

Associated with the transplantation of tendons we have to consider measures which add to the stability of joints as distinct from their mobility; these consist of artificial ligaments, tendon-fixation and arthrodesis.

Silk Tendons.

As an outcome of the use of silk tendons by Lange, several experienced surgeons are using silk ligaments, in order to give stability to the joints and to guard newly transplanted tendons from strain.

It is interesting to inquire what becomes of these silken tendons and ligaments. Anger and Gluck many years ago experimented upon the fate of silk strands used to fortify and bridge separated structures, and they concluded from experiments on animals that in some instances the silk

was displaced by connective tissue, and in other instances the silk formed a trellis-work along which connective tissue grew. Lange, who has had a very large experience, tells us that artificial silk tendons, with use, will develop from the size of a knitting-needle to the thickness of a little finger. His microscopical examinations revealed the fact that the tissue immediately adjacent to the silk had all the characteristics of true tendon. My personal experience (by no means extensive) has not been fortunate. I have operated upon six cases only. Each case healed uneventfully, but later in two instances the silk began to cause irritation at the points of insertion and had to be removed. There was no attempt at the formation of connective tissue in either case, although the strands had remained quite aseptic. In a third case many weeks after operation a suspicious reddening appeared over the knot, which had not been sufficiently hidden, and again the silk had to be removed. In two of the remaining cases the union was stretched, and in only one instance has the foot remained in a desirable position. All this may be due to faulty technique, but I am interested to note that Rich of Tacoma has had to remove the silk in eighteen out of forty cases in which it was used, although only in two cases was there any primary infection.

Against these experiences I must refer to the successes reported by Lange, Tubby, Plummer, Ryerson, Allison, and others. In an interesting summary favourable to the use of artificial ligaments, Bradford and Soutter, in order to prove the strength and permanency of the ligament, state "that in a child of 8, the paralysed muscles largely recovered their function, and that in a man of 23 years, one year after the operation, not only was a foot-drop prevented, but some restoration of function furnished." This only affords additional confirmation of the advantage of preventing strain upon so-called paralysed muscles. We should keep a very open mind upon this question. The fixation of artificial ligaments into bone is so simple and offers so many inducements that if we can feel assured by further experience that the silk will not give rise to trouble the method will have an assured position. For instance, in foot-drop with complete paralysis of the anterior muscles, if the silk will not merely remain but will also develop in thickness and strength, a distinct gain will be conferred. Even when the paralysis is not complete it may prove, as in the cases reported by Bradford and Soutter, an effective means for protecting the overstretched muscles.

Utilization of Tendons as Ligaments.

At present the operation of utilizing the tendons as ligaments has a greater fascination for me. Tilanus first suggested it, and it is capable of very general application. It involves sacrificing the tendon, so that it becomes obligatory to make quite sure that the paralysis is permanent and complete. If the tibials are paralysed, for instance, an incision is made above the ankle and the tendon of the tibialis anticus is pulled upon until the ever-

sion of the foot is corrected. It is then securely fixed under the necessary tension into the periosteum or bone. The tendon may be divided, but often this is quite unnecessary. The deformities of equinus and varus are overcome by similar procedures. This operation seems to me to be more physiological than the introduction of silken cords, for we are using a homogeneous tissue which will not act as a foreign body.

Flail Joints.

In the present stage of our knowledge operations such as I have described are insufficient when we have to deal with a flail joint, over which there is no muscular control, if it has to support body weight. With further and improved methods of using tendon fixations and artificial ligaments, both within and without the joint, we may in time be able to make such joints capable of bearing the strain of walking; at present, however, this is not so. Tendon transplantation unassisted is of very little use at the ankle where several of the muscular groups are totally paralysed. Lange speaks optimistically of producing useful function at the ankle-joint if only three muscles are left to him. In such circumstances he would use two for dorsiflexion and the third as a substitute for the Achilles tendon. I am sorry to say that with so limited a choice I should feel hopeless of success. There is no single muscle which can undertake the duties of the tendo Achillis. When we have a flail ankle to deal with, the only operative success at present is arthrodesis.

Over twenty years ago I advocated the bony fixation of flail joints in the position of greater advantage. At that period the operation had only on rare occasions been performed. I fear that my enthusiasm carried others as well as myself into a somewhat too confident generalization as to its merits and indications. There was then no choice of methods. It antedated plastic work. There is nothing I regret more than that in those days I argued in favour of arthrodesis of the knee in childhood. It is an operation which a more mature experience teaches me should never be performed upon a child. In the adult it gives an admirably firm limb, and under certain conditions it may prove the best thing to be done. There are many who are very grateful to be spared the use of troublesome apparatus. There are others who have come to me whose knees were stiffened in childhood, who beg for a restoration of motion. A surgeon can have no experience more bitter. No knee-joint should be fixed until the patient is old enough to appreciate fully the arguments in favour of and against the operation. In the child it often results in a pseudo-arthrosis; sometimes it develops into a bony flexion, and it is very apt to throw harmful strain upon the hip, the muscles of which so often participate in the paralysis. Even in the adult, if the facts are clearly driven home to the patient, his choice will fall often upon some form of cheap and light support whereby he may be less awkward than if his limb were stiff.

I am prepared to admit that certain people with a blue dangling limb, who retain some power in the psoas muscle, may find ankylosis of knee and ankle combined a real boon.

Arthrodesis of the ankle-joint is quite another matter, and is often of very considerable advantage. It should be usually associated with fixation at the mid-tarsal joint, but should never be performed upon a child under eight; it is better to delay even longer. Vulpius disagrees with me upon this point, but his arguments do not appear in the least convincing. The delay renders ankylosis much more certain, and with ordinary care the deformities and contractures he speaks of will not occur. The deformity which sometimes occurs after this operation is obstinate varus, and is due to faulty technique. Before the operation, if there be any cavus deformity, the sole should be flattened and all tight structures severed. After its completion the bare surfaces of the astragalus should be closely hugged by the malleoli, while the foot should be fixed with flattened sole in a position of slight abduction. This position should be maintained for at least four months. The hip and wrist should never be ankylosed, nor do I see any advantage in operating upon the elbow.

The shoulder requires bony fixation when the deltoid only is paralysed and the scapular muscles are active. The humerus should then be abducted, drawn forward, and slightly rotated inwards, when it will respond at a useful angle to movements conveyed through the scapula.

We must remember that, at the best, arthrodesis is a mutilating operation, and should be the last resort. If a mistake is made it cannot be remedied, and mistakes, unfortunately, are frequently made. Some time ago I saw a boy of 10 whose knee had been arthrodesed because of paralysis of the quadriceps extensor. The paralysis had lasted three years before the operation was performed. As an arthrodesis the result had been a failure because the knees moved, but the profoundly interesting fact is that the quadriceps, so long rested, had recovered, and the knee could be easily and strongly extended. It was a valuable object lesson to all who saw it.

Nerve Crossing.

I have discussed the various methods by which we are able to give immense relief to these crippled children. We can generally avoid deformity, we can always correct it. We can often rectify lost function and make flail limbs firm. Such results are very important, but it would be depressing to feel that we are destined always to travel on these lines—building up by complex mechanism, steel splints without, silk splints within, muscles fixed to new attachments, and joints ruthlessly destroyed. Our thoughts naturally turn to more conservative methods by way of the nervous system. Whether nerve crossing is ultimately to lead to great triumph, or to bitter disappointment, we cannot yet answer without being biassed either by hope or despair.

The many successful cases of nerve suture in man which followed that of Baunders in 1835 has placed this operation upon a sure foundation, and primary suture is to-day a daily routine. Similarly, secondary suture has outlived its experimental stage, and under favourable conditions we can predict success. From this it does not seem a wide step to nerve crossing, and yet it is a momentous one. Perhaps the earliest success was reported by Sick and Sanger, who grafted a portion of the median nerve into the radial. In our own country, in 1895, Ballance met with gratifying success when he united the facial to the spinal accessory. The physiological theory of the neurones was adverse to the experiment, but, as sometimes occurs, the findings of the more exact sciences are modified by the findings of surgical empiricism. The work of Ballance and Stewart was founded on the belief that regeneration occurs in two ways—by a downward growth of axis cylinders from the proximal or central segment, and by essential processes of regeneration in the distal end in the form of a new growth of neurilemma cells, which become part of the new axis cylinder.

I believe the present position of the neurologist is once more the old one—that the axis cylinder grows down from the proximal end, but the neurilemma cells play an important part in its nutrition and assist its downward growth.

Should the distal segment not be sutured or bridged, the impulses to and from the central nervous system cannot travel, and these new parts therefore never become developed, but merely exist as embryonic nerve structures. As Osgood has suggested:

> In the problem which presents itself in cases of paralysis following acute poliomyelitis we find different conditions existing from those obtaining in traumatic or experimental division of nerves, and questions demanding answer at once arise. How essential, if true, is this process of regeneration in the distal or peripheral segment to future conductivity and restoration of full function. Are the nerve trunks, which run to the paralysed muscles, themselves affected by the disease we are considering, and, if so, does regeneration occur in the trunks as the infectious process subsides? If it does not, must we consider this degenerated old nerve trunk as simply a scaffolding or bridge, and suppose that the new axis cylinders of motion, growing from any healthy proximal or central trunk into which the diseased nerve may be grafted, must travel along such a path before we may expect any return of motor power?

These are certainly interesting questions when we compare the almost brilliant results of experiments on animals and the excellent results obtained after primary and secondary suture in man with the hitherto distinctly disappointing results obtained in infantile paralysis. There is no evidence that the virus of poliomyelitis attacks the peripheral nerves. In comparing results of operations on cases of paralysis with those of nerve crossing, after experimental section we must remember that in the former we are dealing with nerve trunks which have for a long time been in a state of disuse.

Every now and again a partially successful case is reported. Spitzy, who has been one of the most assiduous workers in this field, has obtained encouraging results. Partially successful cases have been reported in our country by Tubby and by Sherren, and we have now in literature records of over fifty cases. Warrington and Murray, in a very able and useful communication, report five failures after most carefully conducted operations. The authors suggest that a cause of failure may be the fact that the apparently healthy nerve trunks which conduct energy to the paralysed muscle are less virile, and can draw from fewer motor cells than before the disease; while they may just have enough to supply their own trunk, they have none to spare for another.

Quite recently a new impetus has been given to this subject by the investigations of Stoffel, who, by an elaborate system of dissection, has worked out the topography of the cross section of nerves. He seems to have proved conclusively by very laborious dissections that the nerve branch to each muscle is continued for a considerable distance up the nerve trunk as a separate and distinct nerve bundle. He maintains it to be fairly constant and definite in position, and by a study of the nerve any bundle desired at an operation may be secured. Nerve graftings should be materially helped by this discovery, as healthy nerve tracts which go to supply muscles of minor importance can be drafted for implantation into paralysed nerves. Without this knowledge motor fibres might easily be attached to sensory ones. This is contrary to the previous findings of Bruandet, whose experiments led him to conclude that the motor fibres in a peripheral nerve have no compact distribution, but are diffused and mixed up with all other fibres. If Stoffel's conclusions are correct, our technique will be much simplified. It is obvious that if the surgeon attempts to cure a paralysis of the extensor group of muscles in the leg by splitting off a strip of the internal popliteal nerve and planting it into the external popliteal, there is no reason why the graft should not unite; modern surgery can secure that. Further, as we have seen, our modern knowledge of the regeneration of nerves gives us every assurance that the graft ought to perform its function in conducting nerve impulses, provided the portion split off is a bundle of motor fibres, and provided it is planted into the proper bundle of motor fibres in the other nerve and not into a portion of it which contains only sensory fibres. This is the practical anatomical difficulty which hitherto has remained insurmountable.

When we turn next to the successful cases which have been reported, some are probably cases in which the surgeon has really succeeded in grafting motor fibres into motor fibres. When, however, we look up the details of after-treatment, in several instances we find that part of the treatment consists in fixing the limb in a position in which the paralysed muscles were relaxed, so that they might more readily respond to any impulses sent down

through the regenerated nerve. Here, in my opinion, lies the fallacy, for some of these cases might have recovered, if fixed in this position for a sufficient period, without transplantation. In support of this, Wittek of Gratz, knowing my views upon this subject, sent me a report of one of his cases. It was sent on from the neurological department with a report that the reaction of degeneration was present in muscles supplied by the external popliteal nerve. Relying on this report, he performed muscle transplantation, and the result was successful. A year later the patient came back with an extreme valgus, the internal malleolus touching the floor. On examination the muscles previously pronounced to be hopelessly paralysed were now acting strongly, while the previously strong groups were paralysed from overstretching. There was nothing for it but to reverse his former operation and put his transplanted muscle back where he found it. His remark was, "What a brilliant result to record if I had only done nerve transplantation!" Many of us have had similar experiences in cases where we have been hasty in transplanting muscles.

Although the results of neuroplasty in poliomyelitis leave much to be desired, there is no occasion to abandon hope. We may learn in time the lessons taught by failure, and, what is infinitely more important, take courage from success. A failure depresses, but a success is eloquent of possibilities, and that is just the encouragement we want. Failure should merely set us thinking, and, however critical our mind, it should always remain an open one.

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